

## CHAPTER 5

### UNINTERRUPTIBLE POWER SUPPLY SYSTEM

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#### 5-1. General

An uninterruptible power supply (UPS) system is designed to provide conditioned power which offsets the effects of adverse normal power. There are two types of static UPS - line interactive and true on-line double conversion. A static UPS usually consists of a battery to provide continuous source of electrical power; a rectifier/charger to maintain battery charge and to provide input to inverter when utility power is available; an inverter to provide power to load during normal operation; a static switch to transfer load automatically and without disturbance between inverter and utility power; a manual switch to bypass the static switch for maintenance; input and output isolation transformers and filters to provide appropriate isolation and disturbance attenuation; and monitors, sensors, and control circuits. A flywheel driven rotary UPS is used for applications requiring ride-through of short duration power system outages, voltage dips, etc. The flywheel driven rotary UPS typically does not include batteries, and support times are usually on the order of a few seconds to a few minutes. The use of a generator driven rotary UPS (motor generator or M-G) can provide extended power for an indefinite power outage and also supply air-conditioning and lighting loads.

#### 5-2. Battery and battery charger

Battery power is a group of electro-chemical cells interconnected to supply a nominal voltage of direct current (DC) power to a suitable connected electrical load. The number of cells connected in series determines the nominal voltage rating of the battery is the basic factor that determines the discharge capacity rating of the entire battery.

*a. Storage battery.* The storage battery is constructed of a group of identically sized cells connected in series. The number of cells connected in series determines the voltage rating of the battery. The discharge capacity of the battery is basically its ability to supply a given current for a given period of time at a given initial cell temperature while maintaining voltage above a given minimum value. This capacity is stated in amperes normally abbreviated as A, at a given discharge rate. Most stationary battery cells are rated for 8-hour, 3-hour, 1-hour, 15-minute discharge rates to 1.75 volts per cell.

(1) Lead-acid cells are by far the most popular type of secondary cell. Properly sized, installed, and maintained, a stationary battery using lead-acid cells can have a life expectancy of 15 to 20 years in stationary applications, depending upon plate design, relationship between cell capacity and load demand, cycling, care during installation, maintenance, control of discharges and recharges, and site environmental conditions.

(2) Nickel-cadmium batteries are increasingly applied to emergency lighting and other standby service. The active materials are nickel hydroxide in the positive plate and cadmium oxide in the negative. No gases are generated during discharge, and the gases given off during charging are not corrosive. Initial cost of nickel-cadmium batteries is higher than lead-acid on an ampere-hour (Ah) basis. However, at short rates of discharge, from 90 minutes down to 30 minutes the nickel-cadmium battery discharges a greater percentage of its capacity than does the lead-acid. This high discharge feature is even more important at extreme rates of discharge. In some applications the Ah capacity of a lead-acid battery must be twice the Ah capacity of a nickel-cadmium battery to do the same job.

*b. Charger.* The combination of the charger and the battery becomes a system when it is connected to an electrical load. The load is the equipment that draws DC power from the charger and/or battery. The charger-battery load combination is most efficient only when all of the components are properly matched to each other. The charger converts alternating current (AC) power into DC power that is compatible with the battery's voltage and current characteristics. The charger is the converter section of the UPS which charges the batteries and supplies DC to the inverter.

*c. Floating systems.* When the charger and battery are connected permanently to each other and to the load, and the charger regulates the voltage supplied to the load and the battery, the system is known as a floating battery system. The battery in such systems is mounted normally on a rack or racks housed inside a building or enclosure. The load in this case is the inverter.

*d. Rectifier systems.* The rectifier configuration differs from the float configuration with a rectifier, usually a regulated rectifier, replacing the rectifier/charger. The rectifier is used only to provide power to the inverter and is not used to charge the battery. A blocking diode or thyristor is used to isolate the rectifier from the battery. A separate battery charger is used to maintain the batteries in a fully charged state.

*e. Electrolyte.* The battery electrolyte is a liquid solution of dilute sulfuric acid in which the battery element is immersed for the lifetime of the cell. The ratio of acid weight to water is measured as specific gravity. Pure water has a specific gravity of 1.000. The quantity of electrolyte in a cell is specified in pounds, kilograms, gallons, or liters. Acid electrolyte recommended for most stationary batteries has a nominal specific gravity of 1.215 at 77°F (25°C), when the cell is fully charged. The specific gravity of acid electrolyte gradually drops as the cell is discharged. When the charger resumes operation after a discharge period, the charging process gradually raises the restores the specific gravity of the electrolyte.

*f. Loads.* Specification of the charger and the lead-acid battery depends on the DC load. Each single item of electrical equipment that will be powered by the stationary battery system must be analyzed. Pertinent data required for each item of the load includes: voltage range (window); current or kW draw; duration of operation (time); number of cycles; frequency of use; depth of discharge; and operating temperature range. After this data has been compiled, the battery and charger can be sized and specified.

*g. Environmental conditions.* Environmental conditions and location must also be considered when specifying the battery. Normally storage batteries are sized to perform at 77°F (25°C), but allowance must be made in the calculations for lower temperatures that require more capacity to meet the load criteria. Freezing of the electrolyte results in water crystals forming, but a solid mass is seldom formed. Such crystals damage the plates resulting in reduced life. The charger and UPS performance are adversely affected by altitudes higher than 3,300 feet (approximately 1,000 meters) above sea level or ambient temperatures above 105°F (40°C). Compensations for these factors can be designed into the lead-acid battery system.

*h. Effects of temperature.* Battery capacity is reduced when battery room temperature is normally lower than 77°F (25°C). Battery life expectancy is shortened when the battery room temperature is consistently higher than 85°F (29°C).

*i. Hydrogen gas evolution.* During the charging and discharging process of battery operation, hydrogen gas is formed. Hydrogen gas is very explosive when exposed to open flames, sparks, and cigarettes. The room in which the battery is located should be provided with ventilation, so as to prevent liberated hydrogen gas. Significant amounts of hydrogen are evolved only as the battery approaches full charge.

When the cell is fully charged each charging ampere produces 0.016 cubic feet (.0000453 cu m) per hour from each cell. This volume applies at seal level when the ambient temperature is 77°F (25°C).

*j. Monitoring systems.* Continuous battery monitoring equipment is available which is used in conjunction with a battery charging system. These systems can monitor float charge rate, voltage levels of individual cells or the complete bank, monitor liquid level and adjust charge cycle and rate of charge.

### 5-3. Inverter

The inverter provides three primary functions in the UPS. Inversion is the changing of the DC power to AC power composed of a sine wave free from harmful harmonic distortion [typically 5% total harmonic distortion (THD) or less]. The inverter also provides regulation of the AC voltage to a tolerance level acceptable to the load, typically +2 percent of the nominal voltage. Finally, current-limiting capability is provided by the inverter as a means of self-protection. The inverter used in a C4ISR facility shall be capable of supplying an inrush current of 7 times rated output current without damage or failure to operate.

*a. Inversion technologies.* In the world of industrial inverters, two inversion technologies dominate: these are ferroresonant and Pulse Width Modulation (PWM).

(1) PWM inverters synthesize a sinusoidal output waveform from a constant height, variable width high frequency pulse stream. The pulse stream is stripped of its high frequency carrier (20-50 kHz) by a low-pass filter and reduced to a 120 Vac level through a linear power transformer.

(a) The PWM inverter configuration is referred to as an active regulator. Voltage and current feedback loops gather downstream information and deliver it to a microprocessor based control circuit through a series of amplifiers. The bridge circuit in modern PWM technology normally uses insulated gate bipolar transistors (IGBT) for power switching, although, silicon controlled rectifiers (SCR) could be used in high capacity, lower frequency applications. The IGBT bridge generates a positive and negative pulse train at approximately 3 to 6 kHz. The width of the pulses vary from narrow to wide and back to narrow in each half cycle; this pulse width being proportional to the transistor on-time and to the equivalent root mean square (RMS) AC voltage at that moment in time. The control circuit adjusts the transistor conduction time based on the information received from the voltage and current feedback loops to maintain output regulation. The driver network is a parallel power or darlington transistor array. The positive and negative pulse train is then coupled from primary to secondary of a linear output transformer. A small (line-commutated) LC filter with harmonic traps removes the odd order harmonics from the pulse train to create a sine wave.

(b) PWM inverters offer many advantages when used in computer room applications, including high efficiency due to the use of IGBTs and a linear output transformer, small physical size, low cost, and rapid response to transient load changes.

(c) Disadvantages include limited fault and short circuit current availability (due to the output transformer being linear, a downstream short will be felt on the primary and subsequently the IGBTs; the inverter will shut down to protect the transistors), complex circuitry, high parts count, and intolerance to environmental extremes. These items can contribute to lower long-term system reliability, which is a major concern in an industrial facility, based on user philosophy and load architecture. When used in a computer room application, the advantages outweigh the disadvantages because size, cost, and heat dissipation are more critical issues than long term reliability, primarily due to the relatively short useful life of the computer equipment itself.

(2) Ferroresonant inverters do not use linear magnetics. A line frequency square wave developed by the switch bridge is filtered into a sinusoidal wave shape by means of the non-linear actions of a saturated, resonant secondary winding. The peak current demanded by a non-linear load is supplied by the storage energy in the saturated secondary. The load current is not coupled to the switching bridge. The secondary winding also contains harmonic traps tuned to the 3rd and 5th harmonic. Ferroresonant inverters are uniquely compatible with switch-mode power supplies and do not have to be oversized to provide proper operation.

(a) Ferroresonant inverters are often referred to as passive regulators. Instead of using active feedback and control, regulation and current limiting are an inherent characteristic of the transformer design. The ferroresonant transformer (sometimes referred to as a regulating or constant voltage transformer) is the heart of the ferro inverter. The integrity of the transformer design and quality control associated with its manufacturer have a direct impact on inverter performance and reliability.

(b) The control and bridge circuits in the ferroresonant inverter consist of a simple square wave generator, traditionally using SCRs, however, some designs now incorporate IGBTs. This square wave is then driven into the primary of the ferroresonant transformer. The ferroresonant transformer is nonlinear, designed to operate in the saturation range of its operating curve. The square wave produced by the bridge saturates the transformer core, therefore, the resultant leakage reactance rounds off the corners during coupling from primary to secondary, creating a “pseudo sine wave.” A tuned LC circuit is then employed to maintain the transformer in a resonant state. Harmonic traps are designed to limit the 3rd, 5th, 7th, etc. odd order harmonics resulting in a distortion free sine wave. A compensation winding is used to tighten the regulation of the transformer.

(c) The primary disadvantage of ferroresonant technology is size and weight, and to some extent cost in the higher power ranges. This is due to the mass of the ferroresonant transformer itself. Historically, criticism has also involved audible noise and efficiency, although the new generation IGBT inverters have bridged that gap tremendously.

(d) Low parts count, hence, inherent high reliability and ease of maintenance make ferroresonant inverters a good choice for industrial applications. In addition, the tuned circuit in the transformer secondary stores energy that can be tapped into for downstream fault clearing (most industrial ferroresonant inverters can deliver 500 percent of their rating for 1 cycle prior to current limit). This energy can also be used to meet the demand for non-linear current, resulting in lower distortion in the output waveform when the loads are predominately non-linear. Since the transformer is a current limiting device, it can continue to run when connected to a bolted short circuit. In summary, the transformer can tolerate a great deal of abuse, both operationally and environmentally without degradation in performance.

*b. Harmonic considerations.* Reflected harmonic current from non-linear loads can cause problems for three-phase inverters. Theoretically, in a balanced three-phase system the neutral current should be zero, however, non-linear loads can induce current in the neutral due to reflected harmonic current (primarily 3<sup>rd</sup>, 5<sup>th</sup>, 7<sup>th</sup>, and 11<sup>th</sup> harmonic) even if the phase current appears balanced. This coupled with the high impedance of the inverter can cause voltage distortion in the output waveform. This effect can be significantly reduced through the use of a Scott-Tee output connection rather than a wye because the triplen harmonics are in phase with one another and effectively cancelled, eliminating the 3<sup>rd</sup> harmonic as a problem.

#### 5-4. Transfer switches

UPS transfer switches are often the static interrupter type unless the manufacturer's standard product incorporates the use of circuit breakers necessary for protection and isolation purposes. These breakers or switches are controlled by logic circuits in the UPS inverters or by other circuits included in a common control cabinet or panel. Signals so derived cause closing of the static transfer switch when the monitoring circuits sense the failure of the inverter output or when the UPS module is driven into the "current limit" mode of operation for a preset period of time. Switching speeds as fast as 2 milliseconds are obtainable in standard products of major manufacturers of UPS equipment. UPS systems also usually incorporate a maintenance bypass switch (or breaker) with a make-before-break feature to allow preventative maintenance to be performed on the UPS.

#### 5-5. Instrumentation

Instrumentation provided with the UPS usually includes a local status panel mounted on the UPS enclosure and a remote status panel which duplicates the LED status indicators and switches on the local status panel.

#### 5-6. Motor generator design features

Standard motor generator sets usually provide a ride through of a transient condition for no more than 15 to 30 cycles depending on the load and the mechanical limitations of the motor generator. Usually the limitation is the ability to maintain an output frequency within the tolerance on the load. The Roesel Motor Generator (RMG) is a continuous duty device that provides essential electrical loads with a continuous source of clean, regulated, and isolated 60 cycle power. When a loss or variation of input utility power occurs, the motor-generator continues to supply constant frequency 60 cycle power for a minimum of 15 seconds with full rated load on the unit. At reduced loads it will supply power for up to 45 seconds. When the duration of the power failure is more than 15 seconds or up to 45 seconds at reduced load, the system automatically restarts itself and resumes normal operation when power is restored.

*a. Construction.* The RMG is built as an inverted structure, i.e., the stator is the stationary inner portion with the rotor rotating around it. This provides the best method of obtaining the maximum amount of stored mechanical energy with the least weight in the rotor itself. Exciter coils located on the stator "print" poles on the ferrite lining of the rotor. This is achieved when the exciter heads receive a signal from the generator control and magnetize or re-magnetize the layer of permanent magnet material on the inside rotor surface. The resulting pole pattern is constant in poles per second and thus produces a constant output frequency regardless of rotor speed. The rotor's flywheel effect extends ride-through time from 15 to 45 seconds depending on load. This allows the RMG to provide rated output voltage and frequency independent of the rotor speed during a loss or variation of utility input power. The RMG provides 15 to 45 seconds of ride-through protection for sensitive loads during voltage disturbances. This is ideal where outages are infrequent and protection against voltage sags is a main concern. The duration of most voltage sags is typically between 10 and 20 cycles (60 cycles = 1 second).

*b. Advantages.* The RMG eliminates the need for costly battery plants [required by conventional uninterruptible power supply (UPS) devices] and associated maintenance, space, ventilation, and environmental concerns, etc. The RMG also eliminates the need for costly power conditioning equipment and establishes a separately derived electrical source for protection of sensitive electronic end-user loads such as computer workstations, file servers, data centers, telecommunication systems, and other critical

loads. Finally, the RMG provides total isolation from voltage transients and electrical noise produced by disturbing loads within the facility. It also provides total isolation from interference caused by harmonics (those produced by the protected load and those produced from other loads in the facility).

*c. Disadvantages.* The problems with motor generators are mostly on the output or load side. Very high alternator output impedance can cause substantial voltage dips in response to sudden load changes such as result from large inrush motor starting current, and response to load changes is sluggish in the range of 0.25 to 0.5 seconds. Also, the drive motor may overheat under long term brownout or low line voltage conditions. Motor generator efficiency is relatively low at about 80 percent, so that electrical energy costs over its lifetime may be substantial. Heat dissipation, weight and bulk, and the potential for annoying audible noise are factors that must be considered in motor generator installation. The use of rotating field exciters has eliminated the need for slip rings, with the consequent brush inspection and replacement, but as with any rotating equipment, bearings must be inspected and periodically replaced.

## 5-7. Operational considerations

Operational considerations are another key factor in UPS selection. Efficiency and reliability often depend on the type of unit, the load, and the environment. The higher a unit's efficiency, the lower the operating cost.

*a. Noise.* Noise emitted by an UPS can be a factor, depending on the surrounding environment. In most cases, UPSs placed in computer centers, control rooms, or office-type environments need to operate as quietly as possible. Noise levels vary according to the type of system. UPS manufacturers' specifications generally include noise-level data.

*b. Load types.* The type of load being protected is an important consideration, too. Microprocessor-based equipment may require a different type of UPS unit than other loads. For example, switching power supplies, found in most computers, react differently to certain types of UPS systems. Today's UPS units should be capable of supplying non-linear type loads without derating or degradation in total harmonic distortion. Load size determines what size UPS is needed. Systems usually are sized in kilovolt-ampere ratings. Before selecting UPS capacity, a profile of critical electrical loads should be computed, listing the power requirements of each piece of equipment to be protected. Most UPS manufacturers also recommend allowing for a 25 to 30 percent future expansion factor. Systems generally are available in both single-phase and three-phase models to suit the application.

*c. Application.* Consideration should be placed on the application of the UPS. Computer-room UPS components are more densely packaged to create a smaller footprint. Many times, isolation transformers are removed from the front end of a computer type UPS rectifier/battery charger. Although this usually is acceptable in most office/computer-room environments, it can be a problem in an industrial facility due to the presence of large equipment that may cause disturbances during starting.